A clinician's guide to digital X-ray systems

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J R Soc Med 2001;**94**:391–395

Computers are invading all areas of our lives. Over the next few years there will be major changes in radiology departments around the UK. The invading system is known as PACS (picture archive computer/communication systems). These PACS allow X-rays and other diagnostic images to be captured, distributed and stored in a digital format viewable on computer screens around the hospital. This paper offers a simple explanation of what PACS is and how it works, a discussion of the advantages and pitfalls, and lessons for clinicians learnt from the procurement of our own system.

WHAT IS PACS?

The X-ray-taking process starts with the normal X-ray source and the patient and X-ray cassette arranged in the usual positions. The difference is that the cassette contains a reusable phosphor plate which is sensitive to X-rays but not light. Once the plate has been exposed it is fed into a laser computer reader which captures the image in a digital format. The reader then resets the plate ready for reuse. The phosphor plates are expensive but can be reused several thousand times; they are also more X-ray-sensitive than film, allowing a slightly lower radiation dose to be used. The advantages of this process over silver-film developing are the elimination of the expensive film, the absence of toxic developing chemicals and the speed. Within 30 seconds the image is visible, so if the image needs to be repeated for technical reasons this can be done immediately. If the image is satisfactory then the patient can be released thus improving the throughput of the X-ray rooms. The radiographer then orientates the image on the screen according to hospital protocols and can also alter the contrast and grey scale (a process known as windowing).

The imaging journey

When the image has been optimized the file is archived and additional copies are sent to any computer on the network. Typically the image would be sent directly to the requesting doctor so that it can be seen and acted upon immediately. A copy would also be sent to the radiologists for reporting. Figure 1 shows the imaging journey. Hard copies of any images can be made on film printers or paper if required. Large amounts of printing should be avoided since this is expensive and unnecessary once most areas in a hospital have the computer viewing screens.

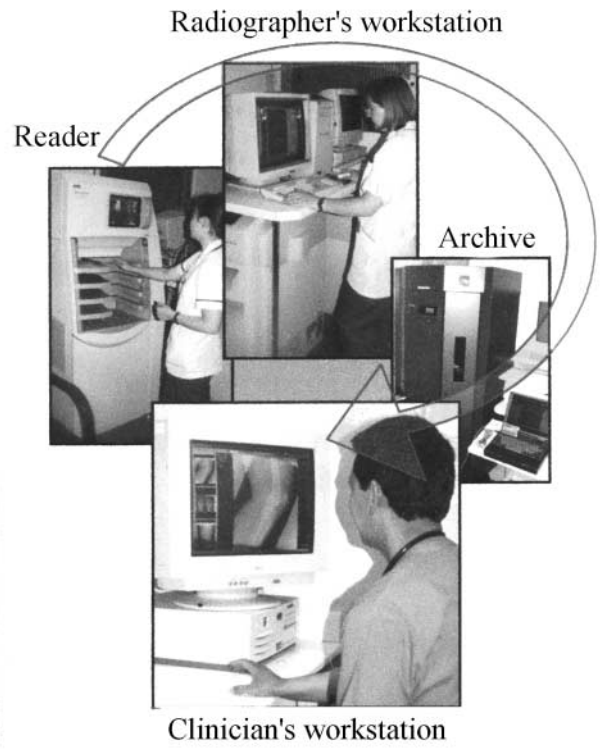

Figure 1 **The digital image journey**

Once the computer image has been seen in the clinical area it can be deleted from that workstation since a copy will have been permanently saved in the main archive. If the image is required for future clinics a new copy can be taken from the archive the night before it is required. This prefetching of anticipated images should allow access times of 2–10 seconds. If an image in the archive is required without notice—e.g. for an accident and emergency (A&E) attendance—it could take 2–10 minutes to retrieve. Images from magnetic resonance, computed tomography (CT), ultrasound and nuclear medicine can also be saved in a PACS archive. PACS are hospital-wide computer systems used by most hospital specialists, among whom radiologists are important but not the only heavy users.

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CLINICAL BENEFITS

For clinicians, the benefits of PACS are:

- Increased availability of images
  - No lost films
  - Multiple copies of the same images can be available in different departments at the same time
  - Increased speed of processing and delivery of the image to the requesting clinician
- Image manipulation to see areas normally lost due to under or over exposure
- Increased speed and quality of reporting[3]
- Possible transmission of images to other hospitals, peripheral clinics, general practitioners (GPs) and clinicians' homes.

For clinicians there are considerable benefits[1] but the full potential will be realized only if the system is carefully tailored from the beginning of the procurement process. The most obvious benefits are that films are not lost (our A&E department has not lost an image in the past 18 months).

Because images can exist in different parts of the hospital at the same time, the houseman's battle with the X-ray department to release unreported films becomes a thing of the past. The images for each patient are catalogued and ordered in a searchable form. This makes it easier to find, for example, all the 'right knee' images for a patient with rheumatoid arthritis whose X-ray packet is 4 cm thick. The potential to send compressed images to a consultant on call at home has intriguing implications. These reduced-quality images sent over a modem would still allow useful operation planning and guidance. In the future it may be possible to send the full-quality image when much faster modems/ADSL become available. With the same system it would be possible to enable GPs to dial into the hospital over a secure link to allow them direct access to certain images.

CLINICAL CONCERNS

Image quality

The first concern expressed by clinicians is whether the image quality is adequate[2]. Most doctors who are familiar with PACS find it eases diagnosis because of the ability to window and zoom into the area of interest. A concern for ward-based clinicians is that the quality of the viewing screen used in clinics and on wards will not be as good as the expensive bright mono screens used by the radiologists. In our own hospital 21-inch Trinitron colour monitors seem to be adequate for most work in A&E provided a higher quality mono screen is available for occasional difficult problems.

Reliability

PACS eliminates the loss or unavailability of images for individual patients, but if the system was to fail it could cause a whole outpatient clinic to be cancelled. System failure is unlikely to cause emergency treatment to stop since each image reader can operate independent of the main system, and can print directly to a printer, thus ensuring immediate access to the image.

PACS archives and networks are just another large computer system as used in industry. Provided they are designed carefully with no single point of failure, and provided routine checking and housekeeping are maintained, there is no reason why they should be any less reliable than systems in banks, airports or defence. The danger in the National Health Service (NHS) is the nibbling cutback philosophy whereby a system is trimmed and then still expected to function at slightly reduced efficiency. These cutbacks are made by removing the duplication of expensive equipment. This lessens the reliability of the system from say 99.9% to 99%. This may sound acceptable until it is realized that 99% reliability means unplanned down-time of 90 hours a year. Clinics could not function with this low level of reliability. Defence systems demand 99.9% reliability (i.e. one day down in 3 years). Unfortunately, that last 0.9% requires doubling-up on expensive computer hardware.

A small number of key staff are also required if these systems are to function reliably. If the staff leave they have to be replaced immediately, not after a money-saving gap of 6 months, as so often happens in the NHS. There is at least one hospital in the NHS which has suffered as a direct consequence of missing key staff.

Speed of system

As computer speeds double every 18 months the computer technology becomes less of an issue. At present a good PACS system should be able to deliver any prefetched image to your screen within 2–10 seconds. This will seem an irritatingly long delay as we become used to the systems but it is probably quicker than the time taken to sort through an X-ray packet containing more than 8 films.

Ease of use

All the PACS software available is intuitive and very easy to use at a superficial level for anyone who is familiar with Microsoft Windows. The best systems have the same customizable diagnostic software on all the workstations in the hospital. All the workstations thus have the same look, feel, and function, allowing the operator to choose which of the advanced searching and display modes to use wherever they are in the hospital. Some PACS have several levels of software comprising a powerful radiologist's diagnostic

application and an unrelated much simpler ward viewing program. This is a less desirable solution since it lacks flexibility for clinicians who use the systems a great deal. The software also looks and feels different in different areas of the hospital, which is confusing.

Digitizing old films

Digitizers are available to archive existing traditional films; however, with even the most automated process it is possible to archive only one film each minute. Thus one must be highly selective in choosing which to digitize.

Restricted image viewing

Traditional films are easily viewed almost anywhere and are highly portable. Images in PACS can only be viewed on computer terminals. It is therefore necessary to have a generous number of terminals around the hospital to compensate. Some changes in work practices may be necessary, such as examining all the films at the beginning of a ward round.

HOW DOES IT WORK?

PACS images are very large files which in the past have proved difficult to store and manipulate. Over the past 3–4 years computer power has improved so much that the images can be handled with acceptable speed, and storage systems are fast enough and big enough to cope with the volumes of data.

In technical terms a typical high-quality chest X-ray image on our system has a file size of 20 MB, which can be compressed by lossless JPEG compression to about 8 MB. It is this 8 MB file that has to be transmitted around the hospital network and stored in the archive. A large (1000-bed) district general hospital will expect to store around 0.3 terabyte (300 gigabyte) of compressed image data each year. The systems that can store this volume of data are based on modern digital tape systems (DLT) or store the data on write-once CDs or magneto optical discs stored in a juke box. These storage systems are improving fast. For example, if these juke box systems move on to DVD, the storage capacity will increase 6-fold at a stroke. A very fast hospital network is required for transmitting these large amounts of data. Typically a central spine of Gig Bit Ethernet or similar is needed, but the local clinic areas can be served by the more familiar fast Ethernet. The workstations have to be fairly powerful PCs to cope with image manipulation, and this requires a large amount of RAM (256 MB would be typical). The screens for viewing the images should be large, flat, high-resolution and bright. A typical ward or clinic screen would be a 21-inch Trinitron colour monitor. For diagnostic work and reporting the requirement is for brighter (50 footLamberts) monochrome screens. Pairs of these screens are often set in portrait viewing position, working together as one.

Even with fast storage systems and fast networks some anticipation of the images is required. For instance, an orthopaedic fracture clinic in a large hospital (100 patients per clinic) requires about 1000 images to be immediately available. Not all of these will be viewed, but any delay in displaying the image will slow down a busy clinic. For this reason most PACS automatically receive a clinic list of all patients expected the night before. This allows all relevant images to be moved into a part of storage (raid) that allows much faster access (2–10 seconds). This prefetching is run at night when the system is not so heavily used. This type of organization also takes the strain off the main archive during the day, freeing it to cope with any unscheduled requests.

In theory, any file can be stored in a PACS archive. In practice only picture files are big enough to cause storage problems. Up to now the images in PACS systems have been mainly radiological; however, clinical photographs of all sorts could be stored in PACS archives. These could include medical photographs, images of histology slides for pathologists or retinal photographs for ophthalmologists.

It is possible to send full-quality images between hospitals over existing high-speed computer links. It is also possible to send selected slices from CT or MR over the Internet to clinicians at home or to GPs via standard modems. Plain radiological images, however, are very large files and standard modems are too slow at present to allow transmission in a reasonable time (30 minutes for a single chest X-ray over a conventional v90 modem). Reduced quality compressed images can be transmitted twenty times quicker and these can be perfectly satisfactory under some circumstances. For example, it is already possible for a registrar to send a compressed image to an orthopaedic consultant at home to allow useful discussion about treatment (a picture is worth a thousand words). ISDN lines can help but are not commonly available and are not fast enough to avoid some reduction in quality for practical transmission times. Over the next 2 years new data transmission systems such as ADSL and cable modems will solve the speed problems for those who have access to them.

FUTURE DEVELOPMENT

Until recently most of these PACS systems have been produced for, developed by and bought by radiologists for use within radiology departments. In the radiology department most images are reported on workstations with two or even four large monitors which allow the comparison of many images simultaneously. On the wards and in most clinics clinicians will be viewing images on workstations on a single screen (21 inch if we are lucky).

Working in this restricted space dictates that the two images to be compared must occupy most of the available screen. This requires easy and accurate choice of the two images for quick comparison before another pair is chosen for comparison. This image selection has not been properly addressed by any of the PACS systems currently available. The bias toward radiology-department use has resulted in poor design of the software interface for use in clinics, wards and theatres. Although the systems in existence can be made to operate in a tolerable fashion, more development work is required to realize the full potential of the PACS in these clinical areas.

To date this has not resulted in many difficulties because hardly any systems are being used throughout entire hospitals. Many suppliers claim they have achieved a filmless hospital; however, when further enquiries are made it usually transpires that the hospital still uses hard copies of images in most wards, clinics and theatres. As yet there are few systems available to be used in orthopaedic theatres, where there is the requirement for templating of prostheses on a radiographic image. This problem has now been recognized by some of the PACS suppliers and solutions are just emerging. However, special adaptations will only be supplied to the hospital if asked for, and that requires procurement input from non-radiology clinicians.

PACS forms an important part of the electronic patient record. However, a great deal of work is required to integrate PACS seamlessly with radiology information, order communications and then into an electronic patient record.

A CLINICIAN'S GUIDE TO PACS PROCUREMENT

A PACS is a hospital-wide computer system, not a radiology system[4]. During the procurement of our PACS we were amazed to find that, on several occasions, radiology departments had bought a system with little or no consultation with the hospital information technology (IT) department. Not surprisingly, there were major problems getting them to interface with the other hospital information systems. This shortsighted approach will make integration into a hospital-wide electronic patient record almost impossible.

All the important decisions that govern how well a PACS will work in a clinic or theatre are made before the contract is signed, and they cannot easily be changed later. All PACS systems should be bought as a hospital-wide system, so the project team should include computer personnel and non-radiology clinicians as well as radiology staff. The inclusion of non-radiology clinicians in the project team will improve the chances of the system delivering a decent service to the wards, clinics and theatres.

If you are a clinician and rely on radiological images in your day-to-day work and hear that a PACS procurement is underway in your hospital, consider the following points:

Project team. Get involved in the procurement of your PACS or at least ensure that the project team contains a representative sample of ward/clinic based clinicians and IT personnel.

Maximize PACS potential for your department. Think about your own department and work practices, identifying how you would gain maximum benefit from this type of system; do not be put off if you seem to be breaking new ground. Teleradiology opens new and useful possibilities that need thinking about even if there are some technological limitations at present. Surgeons should consider its use in theatres, templating, scoliosis and leg alignment views.

Site visits. Go on site visits to similar departments if you can find them.

Specification. Establish a firm and reasoned specification for the system. Carefully work out the number sitting and quality of each workstation. Do not allow the specification to be cut back.

Type of screen. Although the expensive mono screens do provide higher resolution and brighter images they are not as useful for running other non-PACS applications (such as Microsoft Office). For this reason it may well be worth accepting the lower-resolution, cheaper Trinitron colour monitors for wards, offices and some clinic areas.

Single software in hospital. Aim for a single high-function customizable PACS application for the whole hospital. Avoid a high-functionality radiologist's application and an unrelated clinical application with poor functionality.

Transition phase. Plan the transition to the new system carefully, bearing in mind that hard copies of digitally acquired images have the worst of both worlds. They are lower resolution than a traditional film without the advantage of windowing. Hard-copy printing is also expensive. For some departments, particularly orthopaedics where today's images are directly compared with older images, there has to be a transition phase in which all X-rays are acquired digitally and stored in an archive. During this archive-building time (about 6 months) images will have to be hard copied so that all images can be viewed on light boxes, thus allowing valid comparisons to be made with older films. After 6 months a reasonable archive will have been developed, allowing most comparisons to be made on the workstation monitors. The transition time has to be varied from specialty to specialty. In A&E there is very little comparison with old films so the transition is almost instant.

In a fracture clinic an intermediate transition of 3–6 months is more appropriate.

Integrate PACS into electronic patient records. Many PACS providers regard their software as a stand-alone application and refuse to provide performance guarantees if other software is run on the same workstation. As computers become more common around hospitals it is important that the PACS software takes its place on a standard workstation as one of several applications making up the whole electronic patient record. Ideally the different applications should be linked so that a clinician can look at a particular patient's previous clinic letters, the latest blood result, and the radiological images without having to identify the patient on more than one application. Many PACS providers have not realized the significance of this problem.

User groups. Get involved with the user groups. The PACS companies need the guidance of non-radiology clinicians. They may not have realized it yet, but the wards, clinics and theatres of our hospitals have different requirements from the radiology departments and they will have to adapt their systems to meet this challenge.

CONCLUSION

Digital X-ray systems will appear in almost all hospitals in the UK over the next 5–10 years. Every hospital is different and the PACS have to be tailored for each hospital. If the procurement is done well the result will be a powerful system that is a delight for all to use and that will help doctors to treat patients better. Without care and hard work in the pre-contract stage the result will be a mediocre system which works well in the radiology department but impedes clinicians in their work on the wards and in clinics.

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